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An integrated methodological approach to the optimal design and building of dugouts using animal power: A case study in Northern Ghana

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Abstract. ***Length max 150 words****.*

Agricultural activities are the basis for livelihood in semi-arid poor rural areas in West Africa. Harvesting runoff with dugouts and using the water for dry season irrigation can increase agricultural production in arid rural areas and bring additional income to populations. We propose that, in Ghana, small dugouts can be sited, designed and constructed by farmer communities using animal power as the related earthmoving methods are a proven technology and readily available in areas that already use draft animals for ploughing or transport. The design of such structures requires jointly considering biophysical and economic characteristics. An integrated methodological framework is developed to address this problem taking into account the climate variability in the area. A stochastic bioeconomic simulation model is developed and used with an example from in Ghana to illustrate the methodology. The model can be used as a practical tool to design and sit water harvesting structures in semi-arid areas.

Keywords: Irrigation, semi-arid, dugout, optimal design, bioeconomic, Ghana,

JEL codes: Q12, Q18, Q310, Q570, Q250, Q240

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1. Introduction

In semi-arid areas of Africa, agriculture constitute the predominant activity. In fact, in this region more than 60% of the population works in the agricultural sector (FAOSTAT, 2014). However, productivity is among the lowest in the world due to erratic rainfall patterns that reduce potential crop yield and increase the related risks (Day et al. 1992, Ehui and Pender. 2005; Copper et al. 2008). Harvesting runoff water during the rainy season can provide opportunities for improving agricultural production by turning "wasted" water into food (Pandey et al. 2003; Pathak et al. 2009). Particularly, off-season vegetable crops such as tomato, onion or pepper have high value on West Africa markets and can bring substantial additional revenue to rural populations especially to women who are mostly involved in vegetable growing (Laube et al. 2008; Keraita et al. 2008; Faulkner et al. 2008).

However, the standard way of constructing small reservoirs and dugouts using heavy machineries involves large costs that constitute a real financial challenge in developing countries (Pathak et al. 2009). Furthermore, when constructed, the long term viability of these infrastructure is not guaranteed as they usually face maintenance problems resulting in too early degradation and significant reduction of their life span (Venot et al. 2011). An alternative solution is to support communities to build their own reservoir/dugouts using animal power (oxen), local labor and materials (eg. laterite). In other parts of the world, especially in Ethiopia, it has been demonstrated that draught animals can be used for soil excavation and landscape shaping with no major technical problem (Astatke et al. 2001). The Sahelian region has the greatest livestock population in Africa with more than 42 million oxen available in 2004 (Ly et al. 2010). In the region, animal power plays an important role in farming systems and its potential multiple functionalities makes it a cost-effective technology (Gbofu. 1993; Vall et al. 2003). Yet, oxen are presently used almost exclusively for seasonal land preparation in farms and remain unproductive during the rest of the year (Astatke et al. 2001).

Therefore, there is a considerable potential for the use of animal power in dugout building. Such an approach to building small reservoirs has at least 2 main advantages: First, using local material and animal power will save considerable costs compared to the use of heavy energy intensive machineries that usually result in prohibitive costs rendering small reservoirs non cost-effective. Second, from a social point of view, infrastructures constructed in a participatory manner by communities themselves are likely to lead to better appropriation and use making the subsequent management easier and acceptable for the community members (Pretty, 2003; Van Koppen, 2007; Fox et al., 2005; Peacock et al., 2007). Thus, the role of project promoters will be limited to providing coordination and technical advice adapted to local knowledge and skills. However, water harvesting infrastructures even constructed with animal power require adequate design adapted to the context. In fact, the long

term viability of such facilities depend on a range of biophysical (Soil, landscape etc.) and socioeconomic factors (availability of labor force, materials, agricultural input/output prices etc.) that need to be jointly considered (FAO, 2003). Most rainwater storage systems are designed on thumb rule which leads to either oversizing of undersizing them (Dipankar et al. 2009). As a result, they may not be economical.

Few previous studies considered the optimal reservoir design problem. Helweg and Sharm (1983) proposes a model to design reservoirs under a deterministic climatic hypotheses. Assuming a trapezoidal reservoir shape, they determine the optimal dimensions. This study did not explicitly consider rainfall-runoff relations. Srivastava (2001) presented a design methodology for high rainfall areas. This design approach does not consider optimal economic aspects. In the same vein, Sanchez-Cohen et al (1997) describes a few-parameter simulation model for obtaining preliminary design of water harvesting systems. More recently, Panigrahi et al. (2005) analyzed the optimization of the size of on-farm reservoirs based on different indicators. These studies did not consider the variability of the resource. However, rainfall variability is the main factor affecting agricultural systems in semi-arid African countries. Moreover, using draft animals in the construction requires taking into account practical implications namely in terms of the shape of the infrastructure. Also design approach needs to be consistent with the ecological and sociocultural context.

The objective of this research is develop a methodology to design small community dugouts based on animal power while accounting for the biophysical and the socioeconomic considerations of such technology in Northern Ghana. To achieve this objective, a stochastic model considering relevant biophysical and economic parameters is developed. Applying the model to a case study in Upper West Region in Ghana, the optimal size and shape of the dugout are determined by maximizing the Expected Net Present Value of the small dugout reservoir project (ENPV).

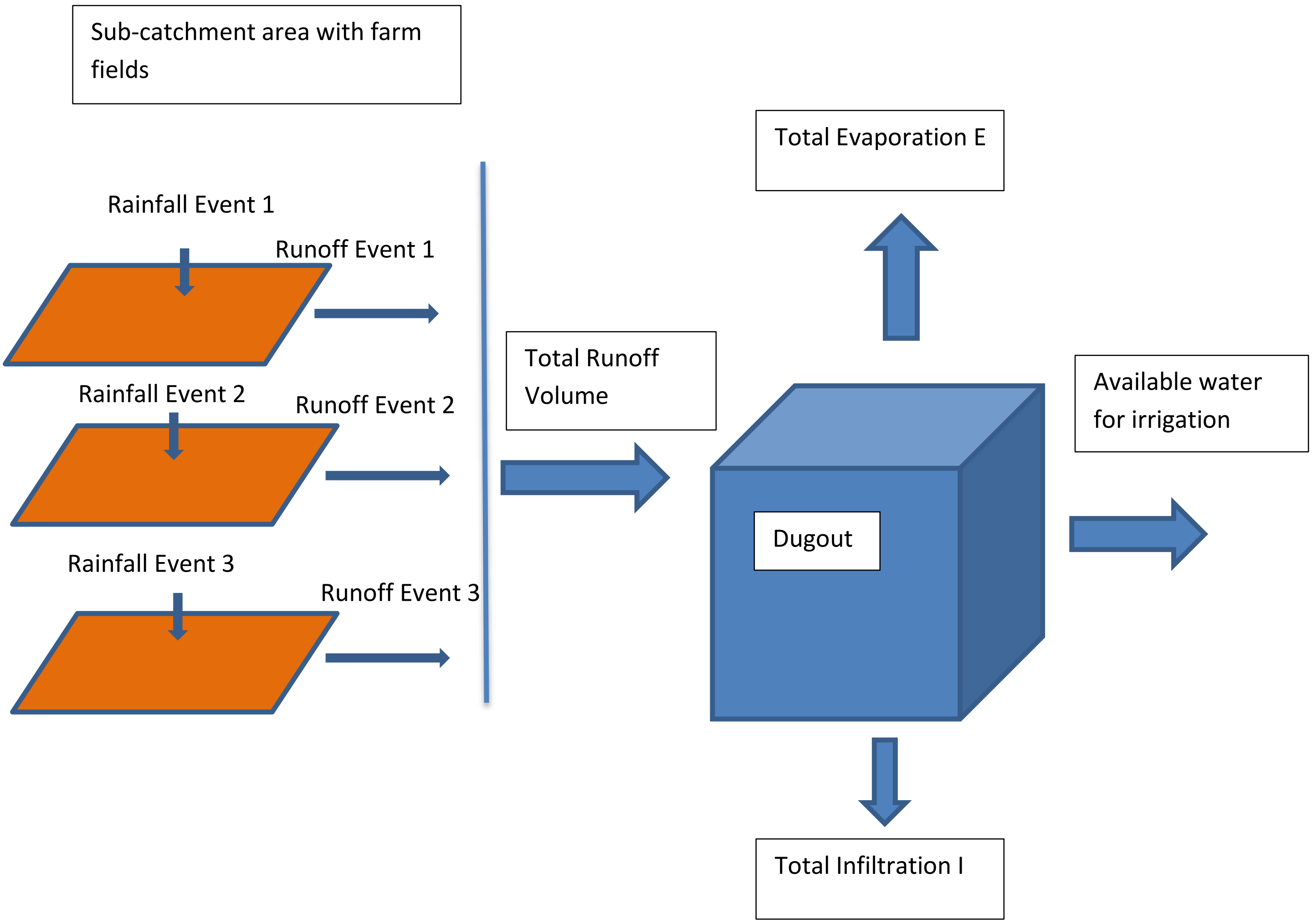
The remainder of the paper is organized as follows: the following section presents the methodological approach. The modeling method is detailed. Section 3 presents the application of the model to a small sub-catchment in Northern Ghana. The final section discusses the implications of our finding and concludes.

2. Methodological approach

According to FAO (2003), the important factors to consider for rainwater harvesting are rainfall, rainfall–runoff relationship, the topography (slope), crop (particularly yield), soil and socio-economic characteristics. Assuming a small sub-catchment area, our methodological approach specifies the

links between the different factors mentioned above. Figure 1 attempts to synthetize these complex links in a visual form. During the rainy season, the sub-catchment area receives rainfall in a stochastic way (event 1, 2…n). Depending on the slope and the soil type of the sub-catchment, a part of the rainfall translates into runoff that is harvested by the dugout. A certain part of the water harvested will be lost through evaporation and infiltration. The remaining quantity is then used for dry season farming. During the dry season, different crops are grown on different plots. The resulting production is sold out at market price.

Figure 1: Conceptual model representing the water balance of the dugout



The main question is how to size the dugout such as to maximize the expected net present value of the dry season irrigation project. The Expected Net Present Value (ENPV) which is a commonly used criteria for projects is calculated. A related question which is to find the optimal rotation between crops is also addressed. The following sections describe in details how the different relationships were represented.

1.1. *Biophysical considerations*

Rainfall Modeling

Both the occurrence and amount of rainfall can be considered to be independent stochastic events. Therefore, the occurrence of rainfall events can be represented as a series of point events in continuous time each having a random amount of water following a marked Poisson process (Benjamin and Cornell, 1970; Rigby and Porporato, 2006). A marked Poisson process is a Poisson process for which each point is characterized by a "mark" which is a variable that may take different values. The number of rainfall events happening for a particular duration follows a Poisson distribution while the amount of water carried for each event follows an exponential distribution.

$$Prob(N_I(\tau) = i) = e^{-\lambda\tau}\frac{(\lambda\tau)^i}{i!}$$

Where *Prob* $(N_I(\tau)=i)$ represents the probability of having i rainfall events between time 0 (which is the reference) and time τ, τ here represents the rainy season. λ is the average number of rainfall during the period or mean arrival frequency. Since the rainfall intensity follows an exponential distribution, we also have:

$$Prob(I_i < x) = \begin{cases} 1 - e^{-\alpha x}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

Where *Prob* $(I_I<x)$ represents the probability of having a rainfall intensity lower than x. α is the rate parameter. $1/\alpha$ is the average rainfall amount (Cox and Miller, 1965).

Losses during rainfall must be considered. Those include for example, interception or the fact that a minimum rainfall level is required to induce runoff. Following Rigby and Porporato (2006), this can be formally represented by adjusting the mean arrival frequency, λ, of the Poisson process to produce an effective arrival rate, or the rate of the Poisson process for which the event is of sufficient depth to contribute to runoff is $\lambda_0= \lambda e^{-\Delta/\alpha}$. Where Δ represents the threshold depth of rainfall necessary to overcome interception and produce runoff.

The new Poisson distribution becomes:

$$Prob(N_I(\tau) = i) = e^{-\lambda_0\tau}\frac{(\lambda_0\tau)^i}{i!}$$

Rainfall-runoff volume relations

The catchment surface area is limited so that that the rainfall can be considered more or less uniformly distributed over the area. Rainfall-runoff volume relations can be simply represented based on the rational formula. Rainfall is considered as point events here. The resulting runoff depends on the area of the catchment or sub catchment considered, the volume of the intensity of the rainfall and its duration, and the runoff coefficient. The runoff coefficient is a function of the soil type and drainage basin slope. Assuming equal duration for rainfalls and a triangular hydrograph, the runoff volume is proportional to the peak runoff flow. The formula (rational method (ref)) is as follows:

$$V_i = a \times Q_i = a \times C \times I_i \times A$$

Where, V_i is the volume of runoff for rainfall event i, C is the runoff coefficient, I the rainfall intensity and A the catchment area.

$$Prob(I_i < x) = Prob(V_i < a \times C \times A \times x) = \begin{cases} 1 - e^{-\alpha x}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

A change of variable, $X = a \times C \times A \times x$, yields:

$$Prob(V_i < X) = \begin{cases} 1 - e^{-\alpha \frac{X}{a \times C \times A}}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

The Poisson process is not affected because transforming effective rainfall into runoff does not affect the number of rainfall for a particular duration.

Volume of water that can be stored

The volume of water that can be stored by a dugout that has no volume constraint (for example an idealized dugout with infinite retention capacity) is the sum of runoff volumes minus the losses by evaporation and infiltration. We assume that evaporation and infiltration are independent of the shape of the dugout. The maximum volume that can be potentially stored by the idealized reservoir is can be represented as follows:

$$Vol(\tau) = \sum_{i=1}^{N(\tau)} V_i - E - I$$

Where Vol(τ) is the volume of water stored, E is evaporation and I infiltration. Vol(τ) is a compound Poisson process and follows a compound Poisson distribution[1]. This distribution is a function of α and λ_0. Let us assume that $F(X) = prob(Vol(\tau) < X)$ is the probability distribution of Vol (τ) and let us denote Cap the capacity of the real dugout (not the idealized), and $Vol_r(\tau)$ the volume of water it contains. The volume of water in the real dugout is:

$$Vol_r(\tau) = \begin{cases} Cap, & Vol(\tau) \geq Cap \\ Vol(\tau), & Vol(\tau) < Cap \end{cases}$$

Therefore, probability of having given water volume saved in the dugout is:

$$\begin{cases} prob(Vol_r(\tau) > Cap) = 0 \\ prob(Vol_r(\tau) = Cap) = prob(Vol(\tau) > Cap), for\ X \\ prob(Vol_r(\tau) < X) = prob(Vol(\tau) < X) for X < Cap \end{cases}$$

The size of the dugout

The size of the dugout can be thought in the following way: we want the dugout to be able to have all the available runoff water volume 100xβ% of the time and forgo some of it 100 x (1-β)% of the time. A choice of a given β defines in a unique manner the choice of a dugout volume. The mathematical formalization is as follows:

$$Cap = X, prob(Vol(\tau) < X) = \beta$$

Helweg and Sharm (1983) assumed a trapezoidal reservoir shape. However, draft animals cannot be effectively used to build a trapezoidal reservoir because animals and the guiding men should be able to go in and out the reservoir to appropriately do the excavation work. Also a purely spherical shape would be too steep to allow effective construction operations. A half-spheroid shape seems to be more appropriate as it allows to reduce the steepness and it is used in dugouts in Burkina faso (DAA, 2014).

$$Cap = \frac{2\pi}{3} ab^2$$

Where a is the depth and b the radius. The radius and the depth must satisfy the following relation (DAA, 2014):

$$\frac{a}{b} < 0.25 \text{ or equivalently } Cap < \frac{\pi}{6} b^3$$

[1] The compound Poisson process distribution has a complicated form. It can be written as $F(X) = prob(Vol(\tau) < X) = \sum_{n=0}^{\infty} F^{*n}(X) \frac{\lambda^n e^{-\lambda}}{n!}$ where $F^{*n}(X)$ is the n-fold convolution of the exponential distribution.

- To have easy access to the water when the level is low
- To ensure the safety of people and children in particular,
- To ensure the stability in time of a total or partial renappage clay to improve sealing

Crop Yield

Crop yields can be defined as a function of irrigation water as water is the most important limiting factor in agricultural systems (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979). There are several ways to represent crop yields (Griffin et al., 1987). We make the general assumption that per area yield increases with water application but at a decreasing rate. Furthermore, a minimum quantity of water is needed for the crop to give any useful yield. Based on these considerations and on productions forms used in other studies in agricultural economics (Tong and Guo, 2013 and Sidibé et al., 2012 for example), our production function is described as follows:

$$Y_k(w_k) = (w_k + \alpha_1)^{\alpha_2}$$

Where $Y_k(w_k)$ is crop yield as a function of water w_k, α_1 is a coefficient (it represents the minimum water necessary to start having production) and α_2 is a coefficient of productivity.

1.2.Economic considerations

Costs of dugout construction

Dugout construction will involve both variable and fixed costs. The variable costs will have to do with the time spent on the excavation and the volume of earth moved per day while the fixed cost will be related to the study, the tools needed for the excavation (scoop and maresha).

$$Costs_0(Cap) = c_d \times Cap + C_d$$

C(Cap) is the total cost of dugout construction as a function of its capacity Cap. c_d is the unit per volume cost of dugout and C_d represent the fixed costs.

Cost of irrigated farming

Growing dry season crops involve a certain number of costs including mainly irrigation costs, land preparation, fertilizer, harvesting, tools and equipment. These costs are assumed to be linked to the area. Costs can be represented as follows:

$$Costs_t = c_{wt} \sum_{k=1}^{n} A_{kt} w_{kt} + \sum_{k=1}^{n} c_{kt} A_{kt}$$

n is the number of crops grown. k and t are indexes for crop type and time. C_{wt} is the per volume cost of irrigation, w_{kt} is the per area water application A_{kt} is the surface area allocated to each crop and c_{kt} is the per area cost for each crop.

Benefits of irrigated farming

Benefits are derived essentially from the crops sold. Therefore, they depend on the different types of crops grown, the price of each crops, the area allocated to each crop and the yield of each crop. At a given time t, they can be represented as follows:

$$Benefits_t = \sum_{k=1}^{n} p_{kt} A_{kt} Y_{kt}(w_{kt})$$

p_{kt} is the price. The other variables have been previously defined.

Time discount

The concept of time discounting is a way of comparing benefits and costs that occur at different times up to the time horizon considered (Pannell et al, 2006). It accounts for the fact that future may be weighed differently compared to the present. The discount rate is denoted r. it is taken into account in the expected net present value.

Risk and adaptation

The risk is on the quantity of water that the dugout retains at the end of the rainy season. This quantity varies according to the amount and distribution of rainfall. However, the amount of water available in the dugout is observed before the irrigation and the land allocation decisions are made. This provides room for considerable adaptation and reduces the impact of the variability of the quantity of available irrigation water. For example, if the farmers observe that only a low quantity of rainfall is available, they can make rational adjustments by allocating more land to the most drought resistant vegetables and more water to crops with higher water productivity.

1.3.Integrated framework

The economic objective is to optimize the expected Net Present Value taking into account all cost and all benefits within the project time horizon. A positive Net Present Value (NPV) indicates a viable project (ref). It is assumed that the water collected in the dugout will be used to irrigate an irrigable area denoted A. A is a function of soil types suitable for irrigation and the proximity with the dugout. Although the economic problem is to calculate the optimal capacity of the dugout, problems of

optimal rotations between different crops according to the available water quantity each year and optimal irrigation intensity for each crop area and each time[2] are implicitly to be solved. This aspect has been ignored in previous studies. We assume the possibility of k vegetable crops k=1…n. these can include tomato, onion, pepper etc. each crop has an area A_k allocated to it. Each crop is irrigated with intensity w_k. Each crop k has a per area crop yield Y_k and per area cost c_k. For year t, the benefit from the different crops is:

$$Benefits_t = \sum_{k=1}^{n} p_{kt} A_{kt} Y_{kt}(w_{kt})$$

The costs are:

$$Costs_t = c_w \sum_{k=1}^{n} A_{kt} w_{kt} - \sum_{k=1}^{n} c_{kt} A_{kt}$$

There is a water constraint and a land constraint. It is impossible to use more than the available water volume Vol_{rt} or use more than the available land area A_t.

$$\sum_{k=1}^{n} w_{kt} \leq Vol_{rt}$$

$$\sum_{k=1}^{n} A_{kt} \leq A_t$$

There is also an initial cost C_t that represents the cost of building the dugout. The expected net present value is defined as follows:

$$ENPV = E\left[\sum_{t=0}^{t=T} \frac{Benefits_t - Costs_t}{(1+r)^t}\right]$$

Where T is the time horizon of the project.

The optimization problem of the expected net present value is:

$$\max_{Cap} E\left[\sum_{t=0}^{t=T} \frac{\max_{A_{kt} w_{kt}} \sum_{k=1}^{n} p_{kt} A_{kt} Y_{kt}(w_{kt}) - c_w \sum_{k=1}^{n} A_{kt} w_{kt} - \sum_{k=1}^{n} c_{kt} A_{kt} - C_t(V)}{(1+r)^t}\right]$$

[2] Here, the problem is formulated in the most complete form. It can be simplified by making assumptions on what choice variables are the most important one. One can assume for example that land area allocated to different crops are fixed.

With the following constraints:

$$\sum_{k=1}^{n} w_{kt} \leq Vol_{rt}$$

$$\sum_{k=1}^{n} A_{kt} \leq A_t$$

The model presented above can be adapted into a simulation model that uses Monte Carlo methods. That is what we do in the illustrative example presented below.

3. Illustrative example

3.1.The case study

The site selected for the case study is the Gyrlli community. This community was selected because of the proximity with a major town (Wa), the availability of draft animals and the willingness of the inhabitants to engage in dugout construction and dry season farming. The climate is of Sahelian semi-arid type with a single rainy season stretching from May to September. Annual rainfall variability is high: it varies between 500 mm and 900 mm (Mofa, 2012). the soils are of Leptosols- vertisols type. Annual mean temperature is 21-32^{o}C, and the annual mean maximum temperature is 40^{o}C (Acdep, 2014). Households are highly reliant on agriculture. Crops grown include in the rainy season include maize, sorghum and millet. Because of water scarcity during the dry season, no significant off-season agricultural activity is currently practiced. Only few women have home gardens where they grow tomato and pepper.

Field visits were made to the community and focus groups were organized in order to understand the possible constraints on availability of draft animals, acceptability of the idea, knowledge in vegetable growing and assessment of the willingness to participate in the project. The result showed that the community and the surrounding villages possess enough draft animals to carry out dugout construction. It also showed that women in the village have knowledge in vegetable growing although at a small scale. The main single constraint to vegetable farming is the availability of water in the dry season.

Fig 2. This map locates the sub-catchment of the study area.

Source: www.lonelyplanet.com

3.2.Empirical specifications

Rainfall and other meteorological data from 2004 to 2010 from Wa station (a town located in the Upper West Region 15 km from Gyrlli community) was used to estimate the parameters of the rainfall probability distribution, the evapotranspiration and infiltration in the dugout during the irrigation period. The rainfall data was adjusted to the theoretical probability distribution previously presented. Using GIS data (Digital Elevation Model), remote sensing technics were used to delineate the sub-catchment in which the community is located and identify its outlet were the dugout is assumed to be built. Rainfall-runoff coefficient was estimated based on Obuobie (2008). Tomato and peppers are the crops considered because they have high value on local markets and women have experience in growing them. Cropwat was used to estimate the water requirement for tomato and pepper for maximal yield. This information is then used to estimate production functions previously presented.

Economic data on various costs and prices for irrigated vegetable crops were obtained from the Ministry of Food and Agriculture (MOFA) of Ghana. Recent surveys in communities in Northern Ghana allowed to estimate the cost function of the dugout. We derive the cost of per volume of earth moved in Ghana at 2 USD/m^3 based on the cost of hiring a pair of oxen and a man to guide them[3]. Costs of scoop and plough were estimated by a survey involving the blacksmiths nearby the

[3] All calculations were made on the basis of 1US Dollar (USD)= 2 Ghana Cedis (GHS) according to the official rate of the bank of Ghana.

community. Estimating that 50 scoops and ploughs will be needed, the fixed cost is estimated at 413GHS[4].

A Monte-Carlo simulation model coupled to an optimization program was developed to do the calculations. A Monte-Carlo simulation method is an algorithm based method that relies on repeated random sampling to obtain numerical results and is adequate for simulating stochastic processes (Robert and Casella, 2005; Carsey and Harden, 2013). It has been used in an extensive quantity of studies (Rahman et al. 2002; Vrugt et al. 2013). Sensitivity analysis was performed to assess the robustness of the result to the variation of parameters like the discount rate.

3.3.Results of the modeling

Figure 2 shows the variation of the ENPV with the size of the dugout. It suggest that the optimal volume is between around 2800 m^3 with an ENPV of 2842 USD at a discounting rate of 5% over a 25 years horizon. The optimal dimensions are a= 4.4 m and b=17.5 m. The optimal dugout size is not sensitive to the discounting rate. However, the ENPV is sensitive to the discounting rate. At 2%, ENPV is 6438 USD and at 8% only 583 USD. The result indicate that the optimal dugout is not the one able to collect all the available rainfall every year as would assume a naïve design but rather the one that can collect it 25% of the time. The total cost of the dugout is 6012.5 USD. The dam can economically allow the irrigation of up to 1.62 ha of land. The cost of most of similar reservoirs constructed using heavy machineries lies between 10,000 and 25,000 USD/ha of irrigable land (Venot et al., 2011). This shows that the animal based method may be a much more economical way to think small rainwater harvesting.

Figure 2: Expected Net Present Value of the dugout as a function of the volume

[4] All biophysical and economic data are available upon request.

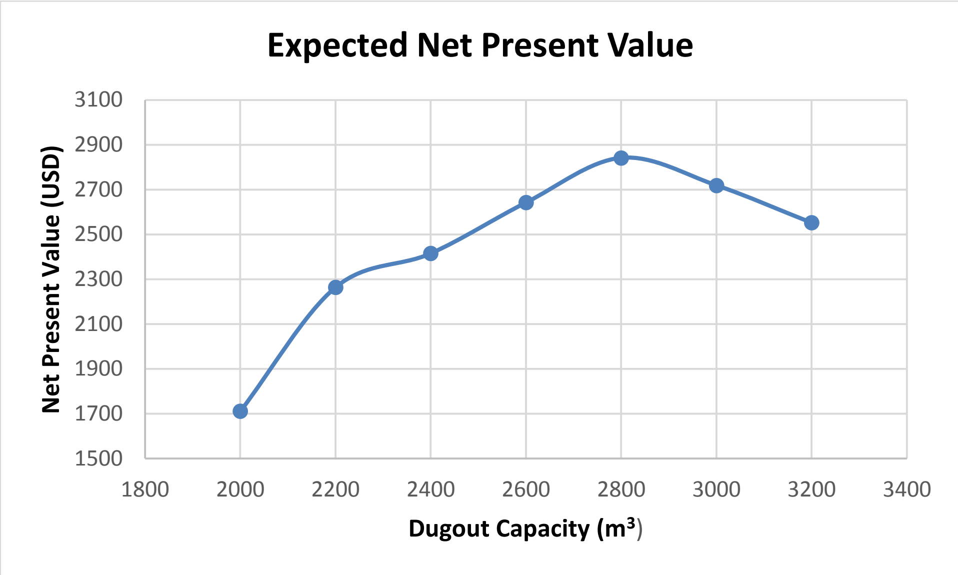


Table 1: Optimal rotation between crops according to water availability

Water Constraint (m^3)	1500	1700	1900	2100	2300	2600	2800
Tomato							
Area (ha)	0.28	0.18	0.11	0.06	0.00	0.00	0.00
Water volume (m^3)	515.17	327.56	195.40	106.78	0.00	0.00	0.00
Irrigation Intensity Useful Volume per area (m^3/ha)	819.56	786.42	825.06	866.24	0.00	0.00	0.00
Production (ton/ha)	4.07	4.03	4.08	4.12	0.00	0.00	0.00
Production (tons)	1.15	0.74	0.44	0.24	0.00	0.00	0.00
Production Value (USD)	241.96	155.35	91.63	49.47	0.00	0.00	0.00
Profit (USD)	102.40	64.97	38.85	21.26	0.00	0.00	0.00
Pepper							
Area (ha)	0.54	0.84	0.99	1.14	1.33	1.50	1.62
Water volume (m^3)	984.83	1372.44	1704.60	1993.22	2274.26	2588.82	2797.74
Irrigation Intensity Useful Volume per area (m^3/ha)	814.90	638.68	727.47	747.04	715.77	722.97	722.89
Production (ton/ha)	3.68	3.51	3.60	3.62	3.59	3.59	3.59
Production (tons)	2.00	2.94	3.55	4.13	4.75	5.40	5.84
Production Value (USD)	509.93	750.66	907.06	1054.19	1214.62	1379.52	1490.88
Profit (USD)	242.44	337.81	420.65	491.79	561.22	638.86	690.41

Optimal rotation between tomato and pepper as a function of water availability in the dugout (which varies annually) is presented in Table 1.The results indicate that in years where the water collected in the dugout during the rainy season is low (1500 m^3), less than a ha should be cultivated (0.82ha). A third of the cultivated land will be allocated to tomato and 2 thirds to pepper. However, in case of availability of abundant water more area should be cultivated and only pepper should be grown. The

economic interpretation is that the marginal economic value of pepper is much higher than that of tomato in when high water volume is available. The rational farmer would therefore adapt by switching from one crop to the other once he/she observes the available water in the dugout. However, there is no much difference between the irrigation intensities (quantity of water to be brought to areas cultivated).

The model results show that water constraint is more limiting to agricultural production than the constraint of suitable land availability. Also, water availability in the dugout is constrained by the size of the sub-catchment upstream of the dugout. This indicates that the selection of the site of the dugout is a crucial step in the design process. Furthermore, the study shows that it is not economically optimal to target the maximum yield as it is often imagined. The target yield should be in line with water availability.

4. Conclusion

This study has developed and applied a theoretical and an empirical simulation model for the optimal design of small community water harvesting systems for off season farming in semi-arid areas characterized by high rainfall variability. The model takes into account both biophysical and economic considerations. In Northern Ghana and in parts of Southern Burkina Faso, many communities still have no access to rainwater harvesting infrastructure because the standard way of building small water harvesting infrastructures is not always adequate. It involves high costs, faces the difficulty to access to communities with machineries, requires qualifies skills to use the machineries and repair them. Because of these reasons, the projects exhibit prohibitive costs (Venot et al., 2012). Our findings show that, in areas where draft animals are available, alternative technological option can be economically feasible. The impact of this cost-effective technology on poverty reduction can be significantly high in Northern Ghana especially for women who are most involved in off-season vegetable growing. Moreover, adopting optimal rotation between crops according to the availability of water is an important leverage to adapt to inter-annual rainfall variability.

The analysis presented here can be extended by including considerations including future climate change. Also the illustrative example presented can be made more realistic by a better field study to identify with a higher accuracy the hydrological conditions of the sub-catchment area. The model presented in this paper can be used as a decision support tool by governmental agencies, NGOs and farmer associations to design and develop economically profitable water harvesting infrastructures.

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